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SYSTEMS ANALYSIS OF LIFE SUSTAINED FUNCTIONS BY BLEEDING

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Hiroshi HOSOMI. *Systems Analysis of Life Sustained Functions by Bleeding.* Kobe J. Med. Sci. 18, *79—96,* June 1972——The complexity of living systems makes selection either a construction of discrete subsystems studied in detail or an overall analysis of a large part of the system. The former leads to an increase in the complexity of the abstract system. In this paper it will be shown that large subsystems functionally isolated by an input variable, bleeding volume, can be analysed as relatively simple abstract systems which enable an accurate prediction of the behavior of the life sustaining systems. Static, transient and frequency characteristics were obtained by a relation between an input and an output. A backward path gain played an important role on the hyperbolical change of an open loop gain against bleeding volume with every regard to constancy of a forward path gain. When time constant obtained from the transient response of the system was 13 sec., it responded like a first order system, but in a case of 8 sec., it behaved like an underdamped system. Thus, time constant is an index of conformability and stability of the systems. The systems under study were quite stable by the aid of Bode 'plots and Nyquist plots obtained from frequency analysis. Due to an unknown condition of the biological 'systems, the 'systems showed a characteristics of a second order system or a first order lead-lag system. A possibility was discussed that made a negative feedback system behave like a positive feedback performance by changing the backward path gain or time constant.

INTRODUCTION

Even if we paid a relevant attention to a number of measurable attributes of each object which was a part of a whole, we could not estimate the behavior of the whole. However, when we set a definite purpose for the whole and assume some sorts of interaction between such objects and relations between the attributes of each object, we could express the behavior as a well defined mathematical formula. The mathematical, but not physical, identity of the attributes of an object and the relations between them introduce a concept—*a system,* which is an abstract entity associated

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with a set of attributes or variables and a set of relations.[1,2,17] Of particular importance in *biological systems* are the optimal conditions of the internal environment for sustaining the life against the external disturbances.[1,2,29] The concept of *control* or *regulation* is implicit in the above mentioned constancy of the internal environment but has not yet developed into an explicit formulation. In the physical sciences, feedback concept and its mathematical expression have been realized in analysis and synthesis for systems of different hardware. Success of the application of the same law to various systems which comprised different attributes of different physical objects, stimulated the application of control theory to fresh fields of study —to the biological systems.[3,8,10,14,18,19,20,24,27]

In the biological systems, we can assume some sort of purpose in its behavior and it can be said that the biological systems could exist by regulating itself to be in an optimum condition for achieving the purpose.[1,2,29] Assuming life-sustaining as the purpose of the biological systems, the subsystems should be coordinated and cooperated each other toward the purpose constructing a functional hierarchy, and the subsystems achieve life-sustaining as a whole.

A difficult problem in systems analysis of the biological object may be isolation of a subsystem or decomposition of a very large and complex system in subsystems that is suitable for study. The complexity of biological systems makes selection of the subsystem inevitable, but there is no standard unit or level to decompose the biological systems. Under these situations morphological entity, such as cells, organs and a chain of organs, may serve to determine the size of the subsystem. This method of decomposition, however, seems to be little contribution to simplifying or representing the whole system as a mathematical model or an abstract system, as was the case of Guyton's model of the long term regulation of the circulation.[10] This is an aspect of systems analysis in which a discrete subsystem is studied in high degree of detail. Another aspect is an overall analysis of a large part of the systems, by which relatively simple abstract systems and a preliminary mathematical model are obtained, as is the case of Grodins' representation of a mathematical model for the cardiovascular dynamics.[7,8] McAdam provided computer simulation of the Grodins' model in a sense of feedback mechanisms.[16] Up to date, there are many studies from the point of view of the application of control theory to the circulatory system[5,7,8,10,11,16,21,22,23,25,26] and to a part of the circulatory system during hemorrhage.[4,6,9,15] Sagawa showed a regular and intense oscillation of the systemic arterial blood pressure, by lowering the mean level of the cerebral perfusion pressure, and explained that changing the parameter made the system unstable.[25,26] However, there are few reports concerning the systems characteristics of the circulatory system as a large subsystem involved in the life sustaining systems.

The author intended to decompose the life sustaining systems by bleeding to obtain a quantitative representation of the relations of cause and effect and to devise a controllable model for extension of life. The abstract system isolated by bleeding from the whole system represents a particular aspect of life sustaining. Other each subsystem decomposed by the other procedures or by the other input variables, f. i. infusion of water, hypercapnia, autonomic unbalance etc, is a representative of the other particular aspects or a functionally isolated unit of the life sustaining systems. Ranges and grades of the isolated unit to an input function may or may not reflect the state of whole systems at that situation.

In the biological systems non-linearities are common and this is a troublesome problem for the analysis, because there is no general applicable method by which the non-linear systems can be described. Therefore, non-linearities must be avoided by any means. One of strategies to overcome these problems is small-signal-analysis which yields acceptable results as linearized systems as illustrated by Stark and Sherman[28] and Sagawa.[25]

Another valuable method for linearization is a careful choice of time unit used in analysis with respect to the time spent at each activity. Decomposition by input functions and time constants were the main procedures used in this paper to linearize system non-linearities. Having isolated a suitable subsystem, an approach to describe input-output relation by the use of transfer functions is a relatively easy and suitable technique for biologists, this paper is concerned with this approach. As the biological systems, however, tend to be multi-input-output systems, an alternative method which identifies a number of input and output variables by a stochastic or matrix method is necessitated.

METHODS

Experimental Animals and Surgical Procedures

The experiments were carried out on 37 adult cats of both sexes, weighing between 2.0 and 4.0 kg. After anesthetizing by the intraperitoneal injection of Sodium pentobarbital (Abbott) in a dose of 35 mg/kg body weight, cats were fixed on an operation table on their back and tracheotomized for the endotracheal intubation. During the experiments, the cats breathed room air spontaneously via the inserted tube. Through the whole experiments, a care was taken to maintain the rectal temperature at about 37°C, using an electric jacket in air conditioned room. After administration of 5 mg/kg body weight of Heparin, the blood pressure in the right common carotid artery was recorded with a pressure transducer (Statham P23AA transducer, Statham, Hato Rey, Puerto Rico). For preparing a vascular by-pass, the abdominal aorta was ligated between the renal and the inferior mesenteric artery or a distance of 2-3 cm below the inferior mesenteric artery, leaving every branches of the aorta intact, and two cannulae were placed in the abdominal aorta just above and below the ligation for both directions. These cannulae were connected to the driving machine which generated input functions arbitrally. Thus, blood from the upper aorta flew to the lower aorta through the by-pass.

Experimental Apparatus and Data Acquisition

The experimental apparatus to generate step or sinusoidal changes in the bleeding volume were designed and constructed by the author. The apparatus used for frequency analysis consisted of an induction motor (1/4 Hp. Hitachi), a variable speed modulator (Miki-Pulley, model LK-110 and Zero-Max, model JK2), a gear reducer box (gear ratios; 1/3, 2/3, 3/3 and 4/3) and a syringe. The gear reducer was linked to the syringe via a crank shaft which transformed cyclic motion to to-and-fro motion. The syringe was connected to the vascular by-pass with two silicone valves. The amplitude and the frequency of the driving function were modulated by changing length of the crank shaft and circling speed of the turn table, respectively. For obtaining step function a shaft connected to a syringe was manipulated by hand. The driving function was transformed to electric signals by a slide resistance attached to the shaft.

Systemic arterial blood pressure was measured by a pressure transducer connected to a cannula inserted into the right common carotid artery. The driving function and the systemic arterial blood pressure were recorded on a pen-recorder (Yokogawa, model 3047) and conveyed to a digital computer (Nihondenshi, model JRA-5).

Data Processing

Input and output measures were processed by an on-line system of the digital computer. Some of the programs, which were written in FORTRAN language for JRA-5, were programmed by the author.[12,18] Two kinds of analog signals, the input and the output functions to and from the biological systems were fed to an analog to digital converter and stored for later processing.

When considering the amplifier feedback control system and the transient response to a step input as shown in Fig. 1-A and 1-B, a number of the static characteristics of a system, such as open loop gain factor, forward path gain factor and backward path gain factor, could be determined from the value of the maximum deviation (y_0) and the steady state error (y_∞) in the transient response.[18] At the moment indicated with an arrow 1 in Fig. 1-B, a backward path element has not yet been in activity, therefore, the block diagram in this instant can be expressed as shown in Fig. 1-C. Then, the input-output relation can be defined as follows:

$$y_0 = kgx_0, \qquad \cdots\cdots ①$$

where kg is a forward path gain, x_0 is an input and y_0 is an output. On the contrary, at the moment indicated with an arrow 2 in Fig. 1-B, since a backward path element has been in full activity, the systems have reached an entirely new steady state. The block diagram in this situation can be represented as shown in Fig. 1-D, and the relation between the input and output variables can be defined as follows:

$$y_\infty = \frac{kg}{1+kgh} x_0. \qquad \cdots\cdots ②$$

Substituting the equation ① into the equation ②, and solving for kgh, we obtain

$$kgh = \frac{y_0}{y_\infty} - 1,$$

where kgh is the open loop gain. The backward path gain or the negative feedback gain in this case is defined as follows:

$$h = \left(\frac{1}{y_\infty} - \frac{1}{y_0}\right) x_0.$$

In the case of response as shown in Fig. 1-B, making y_0 and y_∞ 1 and 0, respectively, a transient part $y(t)$ of any step response can be normalized and defined as follows:

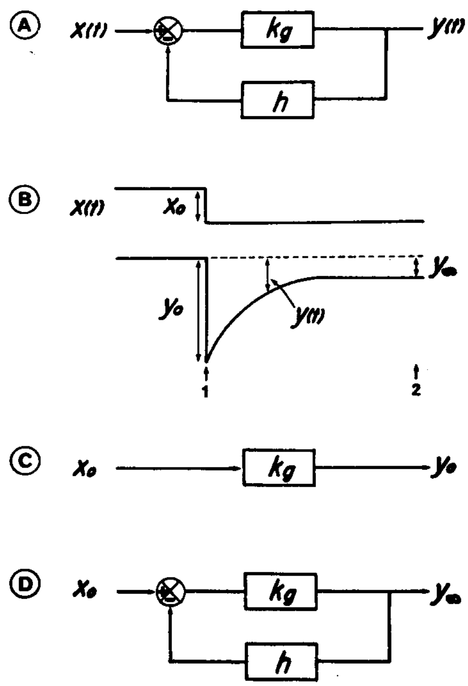

Fig. 1 A : a block diagram of an amplifier feedback control system, B: a schematic representation of step response, C : a block diagram designated at the moment when step function was given and the feedback loop had never been in activity, D: a block diagram with a feedback loop when the systems was in full activity. $x(t)$: an input function, $y(t)$: an output function, kg : a forward path gain, h : a backward path gain, x_0 : the value of $x(t)$ at arrow 1 and 2, y_0 and y_∞: the value of $y(t)$ at arrow 1 and 2, respectively.

$$\frac{y(t) - y_\infty}{y_0 - y_\infty} = f(t),$$

where $f(t)$ is the nondimensionalized response. If a system is a first order one, $f(t)$ is given as follows:

$$f(t) = \exp\left(-\frac{t}{\tau}\right),$$

where τ is a time constant. The most believable value of τ in $f(t)$ was estimated by the least squares method. τ is an index of a conformability of a system. If a system is a second order one, a plotted pattern of $f(t)$ will give a clue of a stability of the systems.

The amplitudes of input, i.e. the bleeding volume used in the experiment, were 5 ml to 45 ml by 5 ml intervals.

In the case of the frequency analysis, the data acquisition was started after the initial transients had decayed. Sampling time was about one fiftieth of each input. Ten cycles of both the input and the output function were sampled and calculated the logarithmic measures of the ratio of input to output amplitudes in db, and the angular differences or phase shift as a function of the input frequency. To avoid the non-linearities of the systems, the input amplitude used or the bleeding volume was restricted to about 0.2% of the body weight. The range of the frequencies of the input used in this experiment was from 0.26 to 9.0 radians/sec.

RESULTS

To study the characteristics of the life sustaining systems, a step or a sinusoidal change of bleeding volume was used as an input. The static and the transient characteristics of the systems were obtained from the static and the transient component of a step response, respectively. The dynamic characteristics were obtained by a frequency analysis.

Static characteristics

An attempt was made in this section to determine the final steady state of the system or the complete equilibrium state of all actions and forces to a sudden bleeding approximated to a step function.

Fig. 2 illustrates two kinds of static responses to the step functions. The open loop gain, the forward path gain and the backward path gain or the feedback gain were processed by on-line system of computer, and the results were plotted against the bleeding volume as shown in Fig. 3. The curves illustrated in this figure seem to be an exponential function, of the type $A \exp(-\alpha t)$. A is the initial value and $1/\alpha$ is the time constant of the function. The mathematical representation in this case was as follows:

$$kgh = 23 \exp(-0.088BV),$$

where BV was the bleeding volume. The forward path gain was less than 1 and remained unchanged (△—△ in Fig. 3), compared with the backward path gain (○—○ in Fig. 3) which showed similar curve to that of the open loop gain (▲—▲ in Fig. 3).

Dynamic characteristics
— transient performance —

This section is concerned with an example of the characteristics of the transient component (the time dependent response) in systems response to a step-wise sudden bleeding.

Fig. 4 shows the nondimensionalized portrayals of the step responses illustrated in Fig. 2. The following first order function can be fitted to the nondimensionalized curve (○—○) as shown by the dotted line (▲···▲) in Fig. 4-A,

$$f(t) = \exp\left(-\frac{1}{13\pm1}t\right).$$

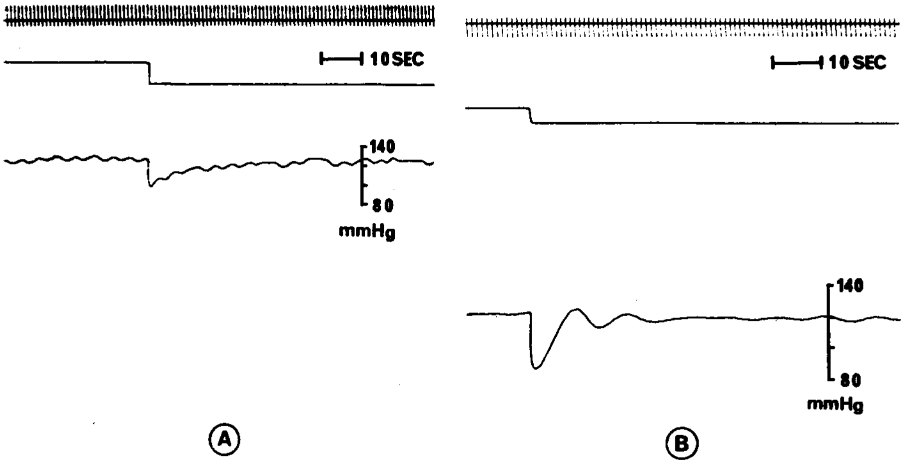

Fig. 2 Examples of step responses
upper tracing : time in seconds, *middle tracing* : a positional change of a piston in the syringe indicating a sudden bleeding or a step input function, *lower tracing*: changes in the systemic arterial blood pressure, A: a first order type response, B: a second order type response. Bleeding volume was 5 ml in A and 6 ml in B. Dead time was negligible in both cases.

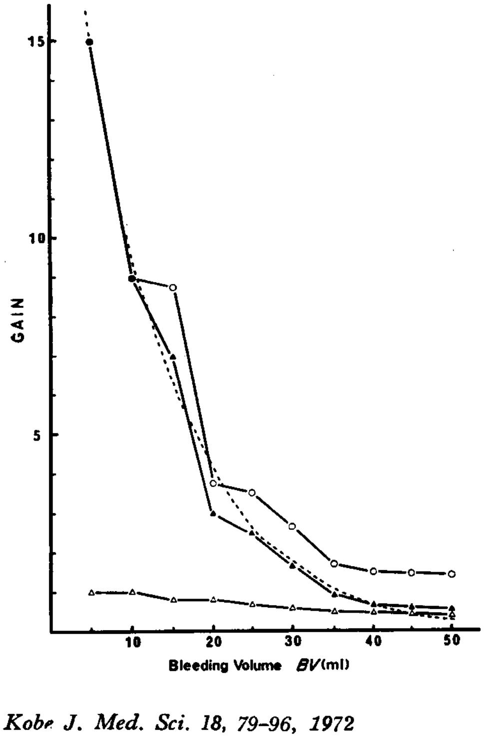

Fig. 3 Static characteristics
Bleeding volume versus an open loop gain (▲), a backward path gain (○), and a forward path gain (△), when the forward path gain in 5 ml bleeding was made 1. The broken line is plots of an empirical equation $kgh=23 \exp(-0.088\ BV)$, obtained from experimental date of the open loop gain (kgh) by the least squares method.

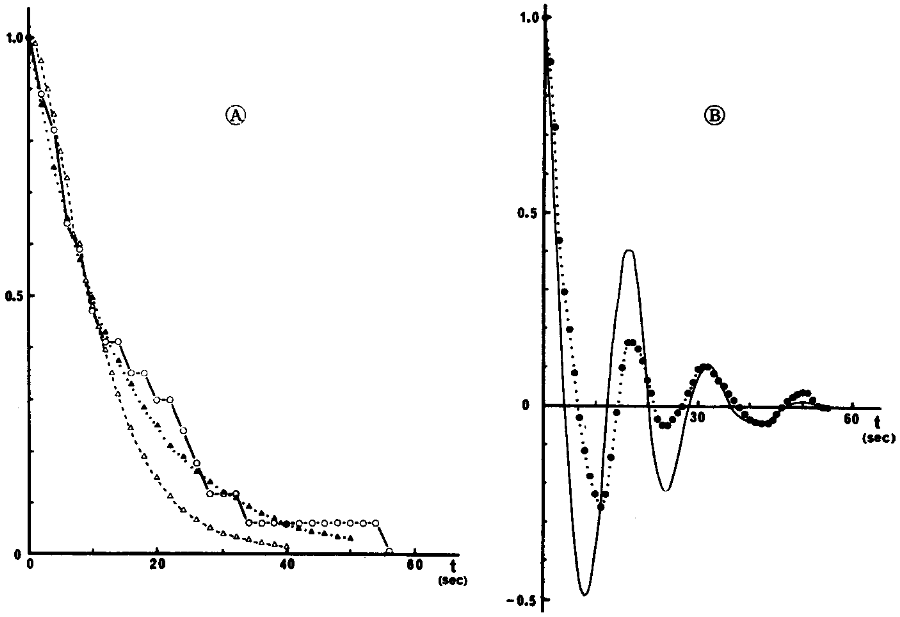

Fig. 4 Nondimensionalized representation of step responses shown in Fig. 2. The smooth line (○) in A corresponds to A in Fig. 2 and the dotted line (●) in B to B in Fig. 2. A : the dotted line (▲) is plots of the equation of $f(t) = \exp\ (-0.07\,t)$, the broken line (△) is plots of the equation of $f(t) = \exp\ (-0.17t)\ (0.17t+1)$, the former fits better than the latter. B: the smooth line is plots of the equation of $f(t)=\exp\ (-0.112\,t)\ \sin\ (\pi/8\ t+\pi/2)$.

Therefore, τ (time constant) was 13±1 sec. On the other hand, if the nondimensionalized curve is considered as a second order critically damped response, which is portrayed by the broken line (△-- △) in Fig. 4-A as plots of the following function,

$$f(t) = \exp\ (-0.17\ t)\ \ (0.17\ t + 1).$$

This equation indicates that the natural frequency (ω_n) is 0.17 and the damping factor (ζ) is 1. It can be clearly seen that the dotted line fits better than the broken line.

The dotted line (●···●) in Fig. 4-B is plots of the nondimensionalized representation of the step response unexpectedly obtained from the other cats as shown in Fig. 2-B. This nondimensionalized curve seems to be an underdamped response and could be expressed as follows:

$$f(t) = \exp\ (-\ 0.112\ t)\ \sin\left(\frac{\pi}{8} t + \frac{\pi}{2}\right),$$

where $\omega_n=0.56$, $\zeta=0.2$, and the equation was portrayed by the smooth line (—) in Fig. 4-B.

Dead time was too small to be considered as seen in Fig. 2.

— *frequency analysis* —

The relationship between the bleeding volume and the open loop gain or the bleeding volume and the backward path gain is non-linear, as illustrated in Fig. 3. In a case in which the relation between the performance of the systems and the input function to the systems is non-linear, frequency analysis can not strictly be applied to that systems. A linear approximation should be employed for such systems. The amplitude of the sinusoidal change of the bleeding volume was made small enough, then, the systems can be treated as a linear system within a limited range, and the frequency analysis can be applied.

Fig. 5 and 6 are the records of the system response when sinusoidal waves with different frequencies passed through a system. Measures of gain (in db) and phase shift (in degree) which were calculated with the digital computer, were

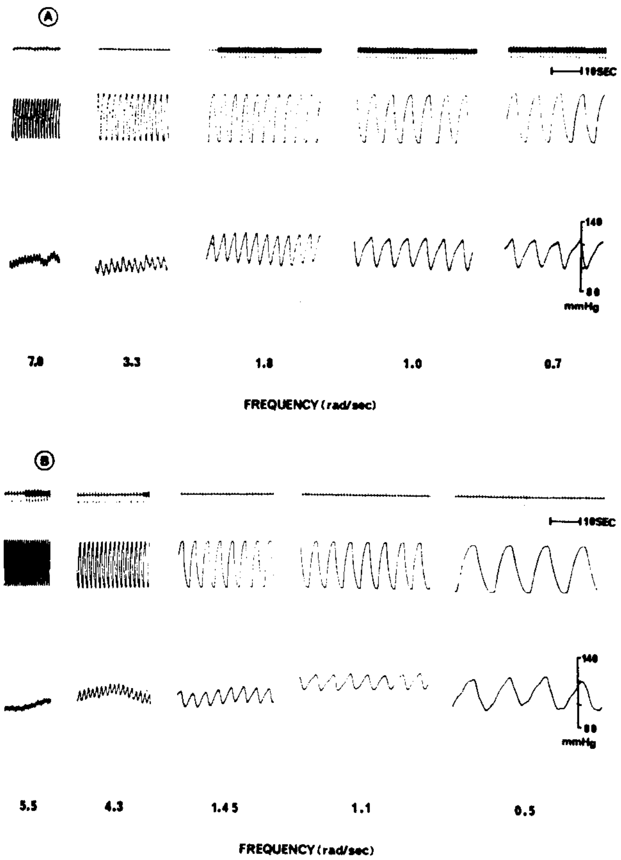

Fig. 5 Amplitude attenuation and phase shift of a sinusoidal wave passed through a system. *upper tracing*: time in seconds, *middle tracing*: sinusoidal changes of bleeding volume, *lower tracing*: changes in the systemic arterial blood pressure. A and B were taken from different cats.

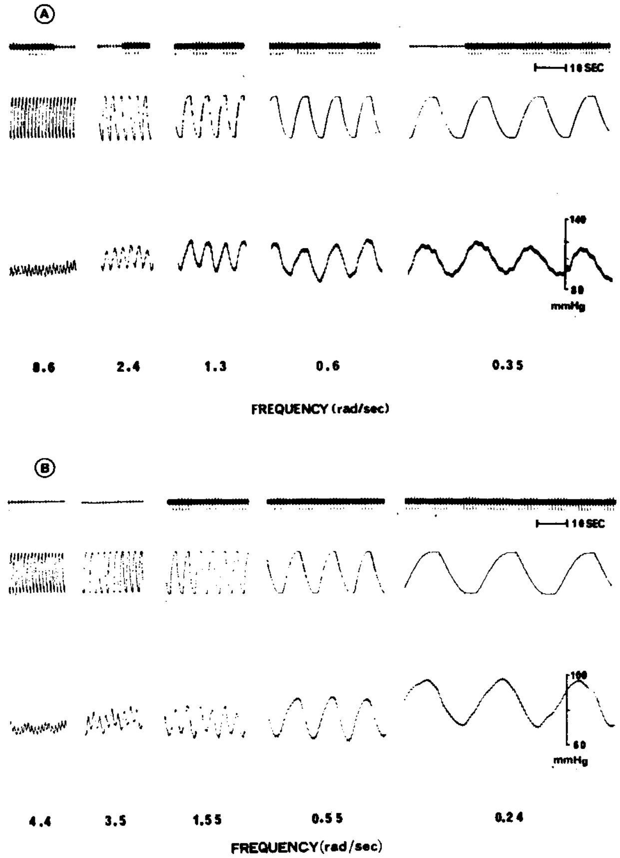

Fig. 6 Amplitude attenuation and phase shift of a sinusoidal wave passed through a system. The explanation for each curve is the same as the legend to Fig. 5.

plotted against logarithmic frequency (in radians/sec.), thus the Bode diagrams were portrayed as shown in A in Fig.7, 8, 9 and 10.

The upper halves of the figures showed a frequency dependent nature of the amplitude ratio or gain of the systems, and the lower halves showed that of the phase shift between input function and output function. Bode diagrams shown in Fig. 7-A and 8-A revealed that the systems under study were a second order system. In Fig. 7-A, the break frequencies were 1.6 and 3.6 radians/sec., so τ_1 and τ_2 were 0.625 and 0.278, respectively. Measures of τ_1 and τ_2 obtained from the diagram in Fig. 8-A were 0.625 and 0.161, respectively. Therefore, the transfer functions of both cases were expressed as follows:

$$\frac{k}{(0.625s + 1)\ (0.278s + 1)}$$

and

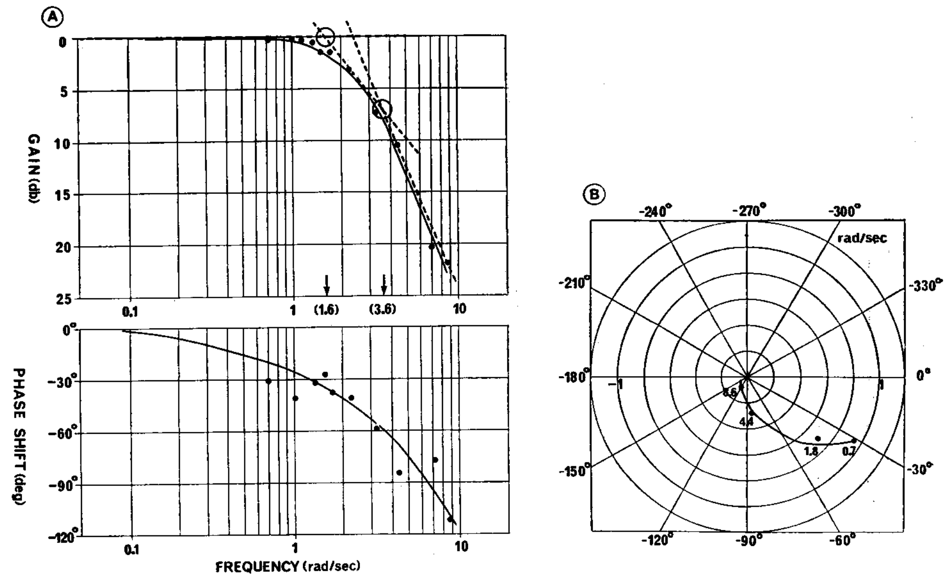

Fig. 7 Bode plots (A) and Nyquist plots (B) in the case of Fig. 5-A. Dotted lines are asymptotes of which slopes are 0, −6 and −12 db/octave. Break frequencies, given at crossing point (○) of asymptotes, are 1.6 and 3.6.

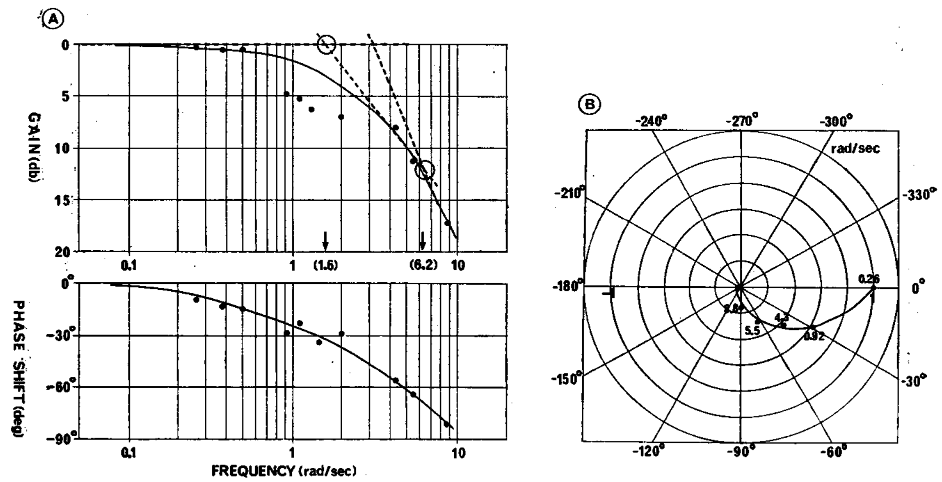

Fig. 8 Bode plots (A) and Nyquist plots (B) in the case of Fig. 5-B. Break frequencies are 1.6 and 6.2.

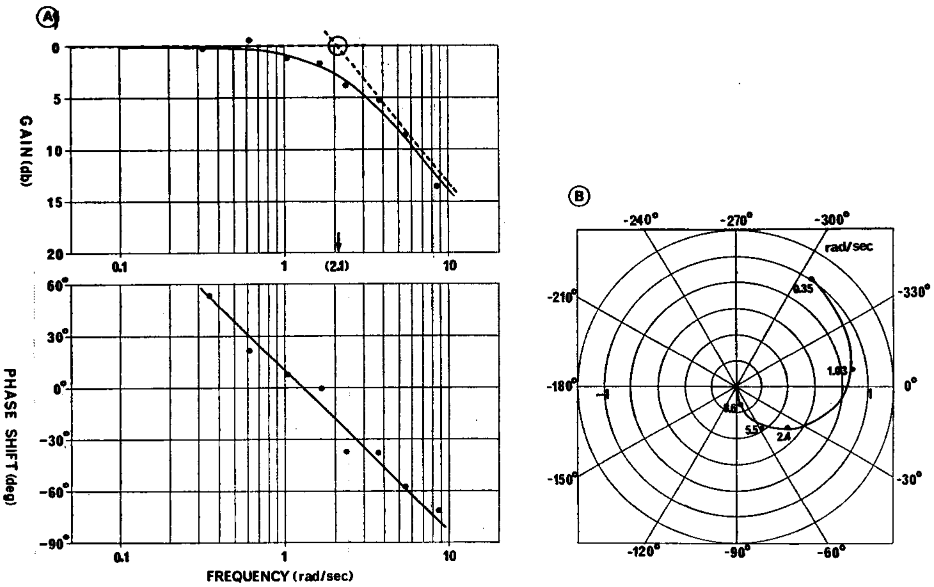

Fig. 9 Bode plots (A) and Nyquist plots (B) in the case of Fig. 6-A. Break frequency is 2.1.

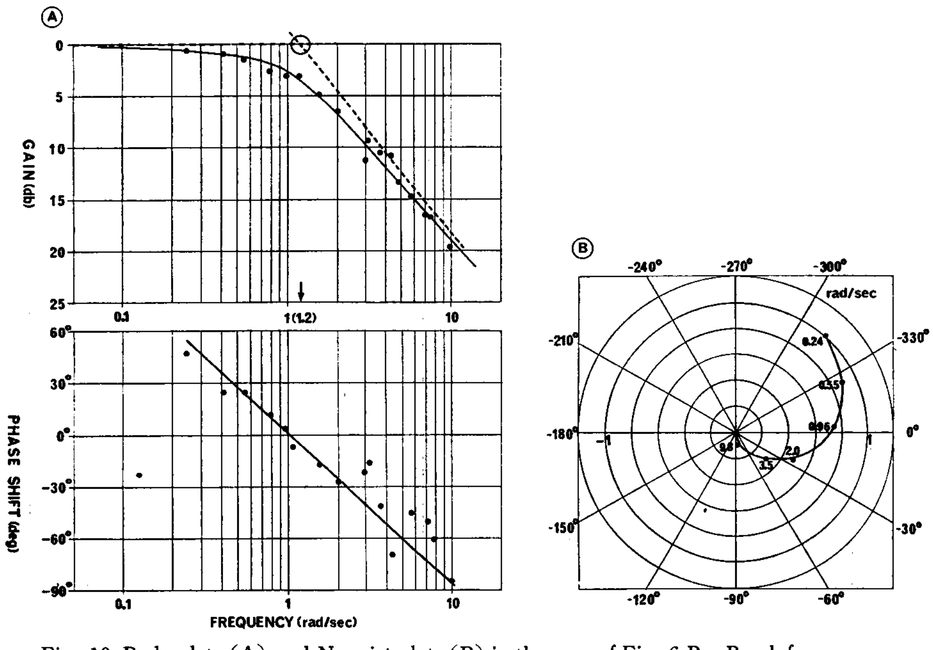

Fig. 10 Bode plots (A) and Nyquist plots (B) in the case of Fig. 6-B. Break frequency is 1.2.

$$\frac{k}{(0.625s + 1)\ (0.161s + 1)}\ ,$$

where k was a constant and the product of all frequency independent terms in the loop. Fig. 9-A and 10-A, which were the Bode diagrams representation of Fig. 6-A and B showed the characteristics of a first order system. τ was 0.476 and 0.83, respectively. The frequency dependent nature of the phase shift in the both cases showed the nature of a lead-lag filter, especially when ω (angular frequency) was less than 1 radian/sec., the phase lag was positive.

To evaluate the stability of the systems, the Nyquist diagrams were plotted. B in Fig. 7, 8, 9 and 10 show the Nyquist diagrams of Fig. 5 and 6. All of the Nyquist diagrams showed that the systems under study were of high degree of stability in the usual case.

DISCUSSION

One of the familiar but vague concepts is the life sustaining systems, which may be defined on the assumptions that the total life activity is an integrated whole of each activity, or is composed of a number of separable autoregulatory systems which could be decomposed by an application of suitable input functions. On the basis of this assumption bleeding was chosen as input functions to decompose the whole systems and to identify the state of the subsystem in terms of the state variables or a transfer function. In this concern, it was a first necessary step for me to find the state variables which expressed a state of subsystem of the life sustaining systems. The main purpose of the present study was to establish a way to pursue such parameters which would be useful in the future to control or to observe the whole systems for extension of the life.

Static characteristics

The solution of a linear differential equation with constant coefficients can be divided into two parts, i. e., the transient component and the steady state component. The static characteristics of a system are the measure of the latter.

The value of the open loop gain in the steady state of the decomposed subsystem changes hyperbolically against bleeding volume as shown in Fig. 3. Because the change of the forward path gain is negligibly small, the backward path gain is to be changed exponentially depending on the bleeding volume, as the forward path gain times the backward path gain makes the open loop gain. The biological systems, in a hemorrhage, will behave to restore the systemic arterial blood pressure to its original level for sustaining the life. If the open loop gain of the systems is large, the steady state error is minified, therefore, it could be said that the system is better in an accuracy. As the decay of the open loop gain as a function of the bleeding volume was relatively steeper, we had to find any method to avoid the dangerous deviation of the subsystem. Control theory indicated that the magnitude of the steady state error depended upon the values of the system parameters. I have not yet established a method to change these parameters at will and to control the systems to be in an ideal state. However, it is certain that these parameters, especially the open loop gain and the backward path gain would be relevant indexes when we find a means to an end.

Guyton and Crowell studied the hemorrhagic shock and explained it as results of a positive feedback phenomenon.[9] Another situation, however, might result in the same catastrophe, in which the system was brought to be unable to possess the activity margin of the backward path element, i. e., the system lost the feedback loop. A response of the system without a feedback loop is directly proportional to an input. In such a system, there is no way to influence the disturbance variables, then, the response would often get beyond the limit of life. If an enough activity margin in the initial stage decreases quickly during the response, the system would suffer from shock in various grades corresponding to the gain margin. Therefore, if the activity margin of the backward path element could be controlled by any means, the hemorrhagic shock could be induced or subsided at will.

Transient characteristics

For single input-output linear systems as linearized subsystems in this case, the identification problem is relatively straightforwarded by determining the transfer function through the transient analysis. As a nondimensionalized response shows only transient component, it makes easy to calculate the time constant of the response. The time constant of every response in a cat to recover from a lowered arterial blood pressure was about 13 ± 1 sec. In this case the time constant may be an index of a speed of a process in which the backward path element is activated and reaches to the state of full activity from zero-state. As the time constant did not change depending on bleeding volume, the speed of the process for the backward path element to be in full activity was almost unchanged in every bleeding event in a cat. A large time constant means that it takes much time for the systems to recover from a state of hypotension, and *vice versa*. In a system with a small time constant, however, the system returns fast to its initial state and the recovery process does not stop there, so that an overshoot would appear. An example shown in Fig. 2-B is probably the case mentioned above. The time constant, therefore, determines a conformability and a stability of the system.

Frequency analysis

The frequency analysis is performed on the basis of comparison of the amplitude and phase differences between a sinusoidal input and output. The differences may be attributed to the number of integrators and differentiators within the system. Differentiation of a sine wave produces, as well known, a positive phase shift or a phase lead and integration has the opposite effect or a phase lag. The results obtained by the frequency analysis could be portrayed graphically by the Nyquist or the Bode diagrams in general. In the case of the analysis of the living systems the Bode plots, which suggest the order of the system, are more appropriate because the living systems are stable in normal conditions. On the other hand, in abnormal or boundary situations stability is an important consideration and the Nyquist plots are more useful. In these connections both diagrams are plotted in this paper.

As dead time (L) in the system under study can be regarded negligible as illustrated in Fig. 2, the delay time, exp(-*sL*) becomes 1. A slope of an asymptote at high frequency in the Bode plots as illustrated in Fig. 7 and 8 is related to the order of the systems. The variation of log amplitude ratio as a function of log ω at a high frequency range is represented by a straight line having a slope -1 for the first order system, which intersects the frequency axis at $1/\tau$. For the first order system, the phase angle increases to $-45°$ at the break frequency and reaches an asymptote of $-90°$ at infinite frequency. On the basis of above statements it is easy to determine the order of the system and represent the transfer function of each system decomposed by bleeding as shown in the section of results.

A diagram in which a gain and a phase shift are plotted on a polar coordinates, is the Nyquist diagram, and it gives an intuitive knowledge on a gain margin and a phase margin as a quantitative index of a stability. If the plotted line crosses the negative real axis to the left of the critical point of unit gain, the system is unstable. Fig. 7-B and 8-B are the Nyquist diagrams of Fig. 7-A and 8-A, respectively. It can be said that the systems in this group are stable.

The other group illustrated in Fig. 9 and 10, showed a characteristic of a first order and lead-lag system. Therefore, as above mentioned, the systems may have differential elements as well as integrators. The differential elements were specified in case that their effects were accentuated at low frequencies because of being unable to adapt due to the time constant at high frequencies. The Nyquist diagrams of this group portrayed in Fig. 9-B and 10-B show that the systems are firm and stable.

Decomposition of systems

In studying the hierarchic systems comprised the coordinated and cooperated subsystems, it is necessary to decompose the systems into some units. Decomposition of the biological systems has often been done with a knife, and many workers observed a purified or simplified function on the isolated organ or a chain of organs. This method is to decompose the systems mainly due to its anatomical structure, implicitly assuming as if a set of elements with anatomical structure equals that with a functional structure, it may be called a hard decomposition or an anatomical decomposition. Many researchers will be in a dilemma that a functional unit localizes in an anatomical unit. On the other hand, if one considers the biological systems are not defined as a set of objects with an anatomical element, but with a functional structure, one could decompose the set of objects with regard to the same functional relation. When we set an input and an output to the biological systems, the measures under observation would be derived by the means that the biological systems decompose their functional hierarchy by themselves. If a researcher uses an unsuitable input or output, he would obtain a fragment of the system which has no relation between other parts of the system in any means. Pavlov decomposed the brain functions and integrated them as a whole on the basis of his dynamical doctrins, using a bell ring as an input variable and a salivary secretion as an output variable in a dog. But he did not actually dissect the brain with a knife to observe the modes of responses of the individual nerve cell which was an anatomical structural unit, because he thought that a function did not reside in some restricted units in the brain, but that a function was a manifestation of relation between excitatory and inhibitory states. Such isolation methods of a set of states can be called a soft decomposition or a functional decomposition by input functions. It can be assumed from the behavior of the isolated subsystem that the functional decomposition cuts across the systems through the hierarchic coordination level.

Each functional unit comprised in the biological systems has own proper biological time process which gives a pattern to a response of a functional unit to an input function. The time in the biological systems could be measured as a time constant in a domain of physical time. It could be regarded that functional units concerned to the same response have almost the same time constant, so they can cooperate each other. By selecting the time constant, a group of cooperated functional units can be isolated. Such a decomposition of the systems can be called a time constant decomposition. In this experiment, both a functional and a time constant decomposition were the main isolation procedures applied to systems analysis. Organs which construct a functionally decomposed system or a system decomposed by a time constant can not be described in terms of anatomy or classic physiology, because the present aim of this paper is to discuss the performance of abstract or mathematical models as a subsystem of the life sustaining systems.

SUMMARY

On the basis of assumption that it was the biological systems that endeavoured to maintain the life sustained functions in the optimal conditions as a whole, the characteristics of the subsystems which were functionally decomposed by application of input variables and by restriction with time constant were investigated and obtained the abstract models.

(1) The open loop gain was hyperbolically changed against bleeding volume and expressed as follows;

$$kgh = 23 \exp\ (-0.088\, BV).$$

(2) It was the backward path gain that played an important role on the hyperbolical change of the open loop gain, because of the constancy of the forward path gain.

(3) In one group, time constant of the response to a step input was about 13 sec. The nondimensionalized response showed a characteristics of a stable and first order system and was defined as follows;

$$f(t) = \exp\left(-\frac{1}{13 \pm 1}\, t\right).$$

(4) In the other group, time constant was 8 sec. The response showed an underdamped nature of a second order system and was expressed as follows;

$$f(t) = \exp\left(-\frac{1}{8 \pm 1}\, t\right) \sin\left(\frac{\pi}{8}\, t + \frac{\pi}{2}\right).$$

(5) Using a frequency analysis, the Bode diagram and the Nyquist diagram were plotted. The systems were quite stable. An example of the type of transfer functions was shown as follows;

$$\frac{k}{\left(\frac{1}{1.6}\, s + 1\right)\left(\frac{1}{3.2}\, s + 1\right)}.$$

(6) There was a group possessing the form of a first order and lead-lag nature. In this group, a differential element was included in the systems and showed prime effects in a frequency less than 1 radian/sec.
(7) A possibility of the production of a hemorrhagic shock by changing parameters in the negative feedback system was discussed.
(8) A biological propriety of the functional decomposition and the time constant decomposition was also discussed.

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